Measuring the Human Pelvis: A Comparison of Direct and Radiographic Techniques Using a Modern United States–Based Sample

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ABSTRACT Seven measurements were taken on a sample of 50 human cadaveric pelves, all white Texans born in the 20th century. Two separate methodologies were used to obtain these data: radiographs and direct measurements. These two methodologies were compared and contrasted, with the relative advantages and disadvantages of each explored.

Results indicate that significant differences exist between the two methodologies. Pelvic height, breadth of symphysis, sacro-iliac breadth ($P = 0.0001$) and anterior upper spinal breadth ($P = 0.0002$) were larger when measured directly. Pelvic breadth, transverse diameter of the pelvic brim, and height of the ilium did not significantly differ between methodologies ($P = 0.2037$, $P = 0.5253$, $P = 0.1752$).

Due to secular changes and inherent intrapopulational variation, taking measurements either directly from modern cadaveric specimens or radiographically on living volunteers in a limited geographic or socioeconomic grouping, rather than from skeletal collections or archived radiographs, may be more appropriate for providing data for current anthropometric applications. Am J Phys Anthropol 103:471–479, 1997. © 1997 Wiley-Liss, Inc.

A number of researchers have measured the human pelvis with the end goal often to determine sex, race, or age of the specimen. Two different methodologies are utilized to obtain skeletal measurements: direct measurements and radiographic analysis.

The majority of work with direct measurements has been done with skeletal remains, for example, the Hamann-Todd collection and the Terry collection. The Hamann-Todd collection was assembled between 1913 and 1933 from defleshed cadavers of known age, sex, race, and cause of death (Rothschild and Rothschild, 1995) and is housed at the Cleveland Museum of Natural History. The Terry collection at the U.S. National Museum of the Smithsonian Institution was compiled from 1914 to 1965 and consists mainly of indigents from the St. Louis area (Murray and Murray, 1991).

Data taken from skeletal collections may not be appropriate for current anthropometric applications. Social and economic changes may, over time, cause changes in the patterns of skeletal growth (Işçan et al., 1994). Intrapopulational variability should also be

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TABLE 1. Cadaveric data (mean ± SD)

	Females	Males
Sample size	20	30
Height (cm)	168.7 ± 11.4	180.6 ± 9.1
Weight (kg)	76.7 ± 15.5	90.5 ± 20.1
Age (years)	65.5 ± 17.6	65.1 ± 13.9

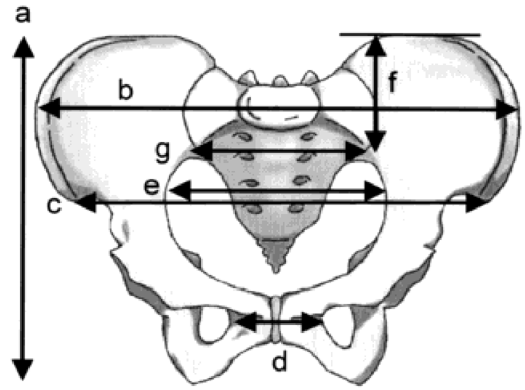

Fig. 1. Pelvic measurements **a.** Pelvic height, right/left: from most superior point on iliac crest to most inferior point on ischial tuberosity, measured parallel to central axis. **b.** Pelvic breadth: maximum distance between lateral margins of iliac crests. **c.** Anterior upper spinal breadth: between lateral edges of anterior superior iliac spines. **d.** Breadth at symphysis: between most medial points on anterior margins of foramen obturator. **e.** Transverse diameter of pelvic brim: maximum distance between arcuate lines. **f.** Height of ilium, right/left: from meeting of sacro-iliac joint and pelvic brim to highest point of iliac crest, measured parallel to central axis. **g.** Sacro-iliac breadth: between points where sacro-iliac joints meet pelvic ring.

considered when using data obtained from skeletal collections.

Alternatively, radiographs of living subjects have been utilized to determine pelvic anthropometry (Brinkmann et al., 1981; Young and Ince, 1940). Raw data obtained with this methodology can contain errors if measurements are not exactly in the plane of the film, or if subject positioning is less than precise. Also if the exact magnification of each measurement plane is not known, only estimates or ratios of dimensions can be reported. An advantage of radiographs is that they can be taken on specifically chosen volunteers to determine skeletal geometry of specific subpopulations, for example, student nurses in the 1930s (Greulich et al., 1939).

The most accurate, modern data would seem to result from direct skeletal measurements on living subjects. Since such an approach is ethically impossible, the closest two methodologies are examined. In this study, radiographic and direct measurements were taken on cadaveric specimens in order to determine whether the two methodologies would yield disparate data. The use of 20th century pelves for measurements, whether direct or radiographic, is emphasized. Such a sample allows for an accurate, relevant set of data that while useful in and of itself for characterizing the modern pelvis, can also be incorporated into a number of anthropometry-based engineering designs.

MATERIALS AND METHODS

Fifty unpreserved, isolated pelvis specimens were obtained from the Anatomical Donor Programs at the University of Texas, Southwestern Medical School in Dallas and the University of Texas Medical Branch, Galveston. Each specimen was of known height, weight, sex, age, and cause of death (Table 1). The sample consisted of 20 white females and 30 white males, aged 30 to 93. Mean age was the same between males and females to avoid the effects of gender-biased increase in pelvic dimensions that occur with advancing age (Hulth et al., 1995).

Each specimen was sectioned superiorly at the L4 vertebra and inferiorly after the proximal third of the femora, and contained the sacrum. The organs were removed and the pelves were dissected of all musculature and soft tissue. Specimens were stored frozen at −20°C until measurements and radiographs were taken.

Seven measurements were chosen in the anterior-posterior (AP) plane (Fig. 1). All measurements were taken to the nearest millimeter with sliding calipers by a single examiner. For both radiographs and direct measurements, the pelves were positioned such that the anterior superior iliac spines made a horizontal plane with the superior border of the symphysis (i.e., a horizontal spino-symphyseal plane). This positioning was chosen to allow correlation between the measurement methodologies, and was not intended to represent accurate anatomical positioning of the supine pelvis. A vertical

TABLE 2. Data from radiographs and direct measurements

Measurement	Radiographs (mean ± SD)	Direct measurements (mean ± SD)	Difference (mean ± SD)	*P* value (paired data, BBT[1])	Correlation coefficient
Pelvic height (average R/L)	212.7 ± 13.3	217.8 ± 14.1	5.1 ± 7.1	0.0001, 0.0001	+0.8669
Pelvic breadth	285.6 ± 20.2	287.2 ± 21.2	1.5 ± 8.5	0.2037, 0.3165	+0.9178
Anterior upper spinal breadth	238.9 ± 19.7	248.1 ± 20.0	9.3 ± 16.1	0.0002, 0.0009	+0.6697
Breadth at symphysis[2]	53.1 ± 6.9	56.7 ± 5.0	3.6 ± 5.7	0.0001, 0.0001	+0.5771
Transverse diameter of pelvic brim	129.5 ± 8.6	128.8 ± 9.4	0.7 ± 7.3	0.5253, 0.5795	+0.6747
Height of ilium (average R/L)	81.1 ± 9.3	79.9 ± 7.9	1.2 ± 6.4	0.1752, 0.0898	+0.7372
Sacro-iliac breadth (SI to SI)	92.8 ± 8.9	112.8 ± 8.1	20.0 ± 10.0	0.0001, 0.0001	+0.3028

[1] BBT, Bradley-Blackwood simultaneous test of variances and means.
[2] Sample size is 44 instead of 50.

spino-symphyseal plane may, however, represent the standing pelvis (Young and Ince, 1940). All direct measurements were taken in planes parallel to the plane of the radiographs. The depths of the planes of four of the direct measurements (anterior upper spinal breadth, pelvic breadth, pelvic height, and transverse diameter of the pelvic brim) were recorded.

Radiographic measurements were corrected for magnification according to a calibration equation in which the true dimension equals the radiographic dimension times the ratio of distances from the x-ray source to the bone, and the x-ray source to the film (Trotter and Peterson, 1967; Moerman, 1981). To verify the calibration equation, calipers were included in the radiographs of one specimen at the height of the table, the transverse brim, and the anterior superior iliac spines. The mean depth of the spino-symphyseal plane was directly measured to be 15.9 ± 1.1 cm, pelvic breadth plane was 12.7 ± 1.2 cm, transverse brim plane was 9.6 ± 0.9 cm, and pelvic height plane was calculated at 7.4 ± 0.9 cm (the average plane depths of the two endpoints of this measurement). For a 101.6 cm x-ray to film distance, this translated into plane magnifications of 1.19, 1.14, 1.10, and 1.08 times, respectively. Since the height of every measurement plane was not recorded, the other measurements were grouped as follows: breadth of symphysis was placed on the transverse brim plane, and sacro-iliac breadth and height of ilium were grouped on the pelvic breadth plane.

The corrected radiographic measurements were compared to those taken directly on the cadavers with a paired data analysis run on SAS software (SAS Institute, Cary, NC) at the 0.05 level of significance. Results of a Bradley-Blackwood simultaneous test (BBT) of variances and means are also reported (Bradley and Blackwood, 1989) as are correlation coefficients. Three additional comparisons of data were performed. Measurements were recorded then recollected on 10 specimens after 1 week to investigate the reliability of measurements with both direct and radiographic methodologies. Direct measurements were also compared to the same measurements taken 1 year previously, in order to determine if the size of the bone had changed (specimens were stored frozen between the two measurements). Lastly, 20 of the pelves were disarticulated at the sacroiliac and pubic symphysis joints, then reconstructed. The original measurements were compared with the rearticulation data.

A comparison was then made between two of the pelvic dimensions (pelvic breadth and transverse diameter of the pelvic brim) and values published in the literature, by means of a Fisher protected least significant difference test at the 0.05 level of significance. This was done to neither validate nor invalidate the previous studies, but rather to determine whether the data were comparable and relevant to the modern population.

RESULTS

Direct and corrected radiographic measurements for each of the seven measurements are compared in Table 2. For four of the seven measurements, the two methodologies produced significantly different data. Pelvic height, breadth of symphysis, sacro-

TABLE 3. Differences between multiple measurements, in mm (mean, SE; percent error)

	Radiographic measurements repeated (n = 10)	Direct measurements repeated (n = 10)	Direct measurements repeated after one year (n = 10)	Direct measurements repeated after rearticulation (n = 20)
Pelvic breadth	−0.9, 0.6227; 0.27%	−0.3, 0.5588; 0.11%	0.1, 1.1686; 0.03%	0.35, 1.0816; 1.22%
Transverse diameter of pelvic brim	−0.4, 0.1633; 0.28%	0.4, 0.9092; 0.31%	−1.4, 0.7630; 1.10%	1.65, 1.1245; 1.26%

iliac breadth ($P = 0.0001$) and anterior upper spinal breadth ($P = 0.0002$) were larger when measured directly. Pelvic breadth, transverse diameter of the pelvic brim, and height of the ilium did not significantly differ between methodologies ($P = 0.2037$, $P = 0.5253$, $P = 0.1752$). A certain amount of "oblique distortion" is to be expected for the pelvic height dimension due to the fact this measurement does not occur in a plane parallel to the x-ray film. Radiographic data would therefore be expected to underestimate the true pelvic height dimension. A high correlation coefficient of 0.8669, however, indicates that a correction factor can be derived to offset the smaller radiographic measurement. In contrast, sacro-iliac breadth had an extremely low correlation between direct and radiographic measurements (0.3028) in addition to significant differences in mean data, indicating that for this pelvic dimension the two measurement methodologies are not interchangeable.

Four repeated measurement experiments yielded data for the dimensions of pelvic breadth and transverse diameter of the pelvic brim (Table 3). Mean differences in data were less than 1 mm for both direct and radiographic measurements of a subsample of 10 specimens. Direct measurements which were compared to data collected 1 year previously were not significantly different for pelvic breadth ($P = 0.9337$) or transverse brim diameter ($P = 0.0997$). It was therefore concluded that the frozen bone was not shrinking, as may occur due to dehydration of defleshed skeletal samples (LaVelle, personal communication). If the bones were indeed becoming smaller this would have been evidenced by a smaller pelvic breadth and a larger transverse brim diameter. Rearticulation had no significant effect on the data (pelvic breadth, $P = 0.7498$; transverse diameter, $P = 0.1587$). This result lends further credence to the accuracy (if not the relevance) of data obtained from skeletal collections.

A comparison of the data from this study to other published data from Caucasian subjects was performed for two of the most commonly reported pelvic skeletal measurements: pelvic breadth and transverse diameter of the pelvic brim (Table 4).

Pelvic breadth of the male Texans, measured radiographically and directly, was larger than any of the other reported data. Female data were more consistent with the other studies, and were not significantly different than Isçan and Cotton (1985), Greulich et al.'s (1939) clinic women, or LaVelle (1995).

Reynolds et al. (1982) subdivided the Hamann-Todd collection into height and weight groupings, by gender. Reported here are the data from "small female," which was the result of Reynolds's combination of small stature/heavy weight (average 151.5 cm, 74.8 kg) and small stature/light weight (153.9 cm, 46.9 kg) specimens, and "medium male," which was the similar combination of the medium stature/heavy weight (172.9 cm, 83.1 kg) and medium stature/light weight (174.4 cm, 67.6 kg) subgroups. All dimensions were measured from a central axis and are doubled for the data reported in Table 4. Reynold's small females and medium males were smaller in pelvic breadth than Tague's (1989) samples from the same collection (Hamann-Todd). Isçan and Cotton (1985), using the Terry collection, reported a female pelvic breadth statistically larger than Tague's, and a male measurement not significantly different.

Moerman (1981), and in her later study, LaVelle (1995) examined radiographs of the left half of the pelvis from a longitudinal

TABLE 4. Two measurements compared to the literature

Pelvic measurement and authors	Female [mean ± SD (n)]	Male [mean ± SD (n)]	Source of data
Pelvic breadth			
Schroeder et al.	276.8 ± 21.4 (20)	294.4 ± 18.6 (30)	Texas cadavers
Iscan and Cotton	277 ± 16.39 (100)	275.07 ± 15.2 (100)	Terry collection
Tague	269 ± 18 (50)	277 ± 15 (49)	Hamann-Todd collection
Reynolds et al.	244 ± 11[1] (28)	266 ± 8[1] (33)	"Small females" and "medium males" from Hamann-Todd collection
Schroeder et al.	277.0 ± 23.2 (20)	291.5 ± 15.8 (30)	Texas cadavers (radiographs)
Reynolds and Hooton	262.38 ± 14.68 (24)	263.62 ± 13.10 (16)	Harvard students (radiographs)
LaVelle	277.7 ± 14.3 (44)	279.7 ± 16.2 (39)	Fels (radiographs)
Greulich et al.	276 (132)		Clinic women (radiographs)
	286.8 (104)		Student nurses (radiographs)
Transverse brim			
Schroeder et al.	131.4 ± 9.6 (20)	127.2 ± 9.0 (30)	Texas cadavers
Iscan and Cotton	132.96 ± 7.91 (100)	124.08 ± 7.86 (100)	Terry collection
Tague	134 ± 8 (50)	130 ± 8 (50)	Hamann-Todd collection
Reynolds et al.	124 ± 6[1] (28)	122 ± 5[1] (33)	"Small females" and "medium males" from Hamann-Todd collection
Schroeder et al.	133.4 ± 9.4 (50)	126.9 ± 7.1 (50)	Texas cadavers (radiographs)
Caldwell	135 (73)	130 (43)	Hamann-Todd cadavers (radiographs)
LaVelle	133.9 ± 6.9 (46)	127.5 ± 6.6 (42)	Fels (radiographs)
Young and Ince	131 (500)	121 (50)	London obstetric clinic women, men (radiographs)
Reynolds and Hooton	128.29 ± 6.68 (24)	121.79 ± 9.03 (19)	Harvard students (radiographs)
Greulich et al.	125.4 (132)		Clinic women (radiographs)
	121.9 (104)		Student nurses (radiographs)
Thoms and Greulich	122.9[2] (200)	118.2 (69)	Students (radiographs)

[1] Standard deviations for hemipelvis measurements rather than whole.
[2] Estimated based on percent of each pelvic type in 686 women, multiplied by mean value for each pelvic type in 200 women.

growth study done by the Fels Research Institute in Ohio. Subjects were born between the years 1928 and 1941 into "well-educated, white middle-class families within twenty-five miles of the city of Dayton" (Moerman, 1981, p. 35). Twenty-three follow-up radiographs taken on subjects between ages 19 and 22 showed that mean pelvic measurements increased less than 1 mm after age 18 in both males and females; therefore, data from 18-year-old subjects were concluded to accurately represent the adult pelvis. LaVelle's women were very similar in pelvic breadth to Gruelich's 1930's clinic women. Interestingly, there was a large difference between Greulich's clinic women and student nurses. These nurses were reported to come from "a somewhat different racial stock and a more privileged economic class" (Thoms and Greulich, 1940, p. 56). If socioeconomic factors were the most significant predictor of pelvic size, one would expect LaVelle's women to have been closer in pelvic size to Greulich's student nurses, rather than the clinic women. Reynolds and Hooton (1936) radiographed Harvard and Radcliffe students and found a pelvic breadth smaller than in all of the studies other than Reynolds et al. (1982). Considering that some of Greulich's student nurses were in fact from Radcliffe, such a large difference between these two results is surprising. Intrapopulational variation and sampling methodology may therefore have a large effect on the resulting data.

The work of both Tague (1989) and Reynolds et al. (1982) can be closely compared to radiographic work done by Caldwell et al. (1939) when examining transverse brim diameter (pelvic inlet), since these researchers all used the same skeletal collection (Hamann-Todd). Caldwell's female data are extremely similar to Tague's, and both are larger than Reynolds's small female data. This further leads us to believe that sampling is the cause for the differences between Reynold's reported female data and those of either Caldwell or Tague. In a comparison of Tague's transverse brim data to that reported by Işçan and Cotton (1985) with the Terry collection, females were not signifi-

cantly different but Tague's Hamann-Todd males were larger.

Transverse brim diameter measured on females in the current study did not significantly differ from data reported by Tague, Isçan and Cotton, or LaVelle, either radiographically or directly. Radiographic female data were larger than those reported by Young and Ince, Reynolds and Hooton, Greulich et al., and Thoms and Greulich, while direct female transverse brim data were larger than Reynolds et al. For Texan males, direct transverse brim measurements did not differ from Tague, Caldwell et al., or LaVelle. Radiographically, males were not different than LaVelle. Both direct and radiographic male data were larger than reported by Young and Ince, Reynolds et al., Isçan and Cotton, Reynolds and Hooton, Greulich et al., and Thoms and Greulich.

DISCUSSION

Drawbacks exist with both radiographic and direct measurement methodologies. Measurements taken from radiographs are limited to those in the plane of the film. Error of up to 17 percent may be introduced if the pelvis is positioned at an angle (Moerman, 1981), and rotation will cause an underestimation of the true dimension (Bohrer and Daniels, 1969). Also, the degree of magnification will increase in proportion to the distance between the plane of measurement and the film. For example, the distance between the anterior superior iliac spines will be magnified greater than the distance between the ischial spines. A radiographic measurement, however consistent, may not reflect the true pelvic measurement if the magnification is estimated rather than precisely known.

In 1947, Heyns collected pelvic brim measurements on 17 female and 3 male Bantu dry pelves both directly and radiographically (corrected for magnification). Mean female transverse brim measurements were smaller radiographically than directly ($P = 0.0188$), while males were not significantly different between methodologies ($P = 0.5422$). Heyns reasoned that since the ileo-pectineal line cannot be accurately represented on an x-ray, transverse brim diameters taken radiographically will be smaller than the true dimension. In a differing opinion, Allen stated in his discussion about standardization of radiographic pelvic measurements: "The transverse diameter need not detain us, there being no dispute as to any feature of it" (Allen, 1947, p. 50). No difference between the two methodologies was identified in the present study for transverse brim diameter.

Trotter and Peterson (1967), in a study of direct and radiographic measurements of transverse diameter of the femur, found a coefficient of reliability of direct measurements taken 2 months apart to be 0.996; radiographic measurement reliability was slightly less: 0.973. In another study comparing direct and radiographic measurement techniques, Gilliam and coworkers (1994) measured pelvic angle on 15 patients. The correlation between the two measurements was 0.85 for one radiologist, 0.68 for another. The authors reported that poor x-ray quality may be a source of error, and that direct measurements may more truly reflect the actual pelvis.

Direct measurement techniques have their own set of difficulties. For those studies which utilized skeletal remains to acquire interpubic measurements, the pelves were either mounted in three dimensions or articulated using a rubber-banding technique (Tague, 1989; Isçan and Cotton, 1985). The rearticulated skeletons were then measured directly. This methodology introduces the possibility of error in three-dimensional reconstruction. Lack of true articulations and inaccuracies in anatomical positioning of the bones relative to each other may affect the resulting data. The results of the present study of a small sample of rearticulated pelves (n = 20) indicated no difference in pelvic dimensions. Artificial physical disarticulation is a different process, however, than degeneration of the joints themselves. The complete absence of cartilage in skeletal collection samples may cause a difference in rearticulation data. For some archaeological samples, the bone itself may be too fragmented to be accurately rearticulated (Sibley et al., 1992). Alternatively, data can be presented from isolated structures, for example the hip bone (Pellico and Camacho,

1992) or sacrum (Flander, 1978) rather than from a rearticulated pelvis.

A question of validity exists in the use of data from skeletal collections for current anthropometric applications. Skeletal changes occur over time; the question of interest is, what length of time is necessary to produce significant differences? Webb and Suchey (1985) questioned the relevance of data from skeletal samples prior to the 1920s noting that conditions such as the introduction of oral contraceptives and the addition of vitamins and nutrients to food may have had an effect on skeletal development. Even more recent changes have been suggested. Isçan and coworkers (1994) compared post-World War II Japanese skeletons to an earlier study by Hanihara of prewar skeletons from the same sample (Jikei Collection, Tokyo) and found that length of the tibia had increased by approximately 13 to 15 mm in females, 7 to 9 mm in males, whereas tibial shaft circumference was unchanged. To continue the Japanese example, Greulich (1976) found that between the years 1900 and 1970, average stature of 20-year-old males increased by 7.9 cm (4.9%), 20-year-old females increased by 8.6 cm (5.8%). A closer look must be taken at such secular changes before assuming all data from skeletal collections are applicable to modern populations.

Moerman (1981) found that ilium height (measured from the most superior point on the iliac crest to the inner acetabular wall) was correlated with combined stature and weight for both males and females ($P < 0.001$). Moerman's ischium height, the distance from the inner acetabular wall to the most inferior point on the ischial tuberosity, was significantly correlated only in females ($P < 0.001$). These two measurements combined form a dimension similar to pelvic height. It would seem likely that pelvic height is larger in the modern population. Pelvic breadth (defined by Moerman as maximum crest breadth) was correlated with combined stature and weight for males only ($P < 0.001$). Moerman's males had a smaller stature and weight (177.5 cm, 70.1 kg) than the Texans in the current study; therefore, it is not surprising that both the radiographic and direct measurements of male pelvic breadth were larger in the Texans than in any of the other reported data, or that female data were more consistent with the other studies.

An example may be illustrative whereby a modern anthropometric application has relied on data that may not represent the population of interest. The data from Reynolds et al.'s (1982) Hamann-Todd "medium males" has been used by the automotive industry in the design of anthropomorphic devices (Reynolds et al., 1995). As the reader will recall from the previous discussion, Reynolds's data were significantly smaller in pelvic breadth and transverse diameter of the brim than the Texans. While it may be of interest to provide a conservative estimate of pelvic size for this particular application, these data may not accurately reflect the true "medium male" driving population that the anthropomorphic device was designed to mimic.

Age of the subjects at the time of measurement may also be an important consideration before utilizing pelvic data for a particular application. Hulth et al. (1995) measured pelvic radiographs of 116 Swedish women and 100 Swedish men divided into three groups according to age. Transverse diameter of the pelvic brim was significantly greater in the 40- to 59-year-olds as compared to the 18- to 39-year-olds (males, $P < 0.004$; females, $P < 0.001$). This dimension was also larger in the oldest age group as compared to the 18- to 39-year-olds (males, $P < 0.031$; females, $P < 0.001$). No significant differences were noted between the 40- to 59-year-olds and the greater than 60-year-old subjects. So while the "adult" pelvis may occur at age 18 to 22 (Moerman, 1981), significant changes in the pelvis may be occurring much later in life.

The present study demonstrates that current, accurate pelvic anthropometric data can be acquired not just from skeletal collections or archived radiographs, but directly and radiographically from cadaveric specimens. One drawback to taking measurements from cadavers is that sample size would tend to be smaller because of the large amount of time and effort involved in specimen preparation and storage. Small sample size is a major criticism of anthropometric

studies (Arsuaga and Carretero, 1994). However, the advantages of direct measurements of modern specimens may balance out this lack of a large sample. Studies of living subjects may continue to be essential, however, in acquiring sufficient amounts of data on younger adults.

In conclusion, current anthropometric applications may require the use of a modern human sample. Study of the skeletal anatomy of the human pelvis can be achieved with either carefully corrected radiographic measurements of living subjects or direct measurements of cadavers. For pelvic breadth, transverse diameter of the pelvic brim, and height of the ilium, the two methodologies do not produce significantly different data. Due to a high correlation coefficient, the pelvic height measurement may be scaleable between methodologies. Breadth of symphysis and anterior upper spinal breadth, both larger when measured directly, have slightly lower correlation coefficients (.5771, .6697) and may not be as interchangeable between measurements. Sacro-iliac breadth appears to be a completely different dimension when measured directly as opposed to radiographically. A consensus should be achieved as to which methodology is most accurate for each of the pelvic skeletal measurement, so that future data may be more precise and relevant to the current population.

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LITERATURE CITED

Allen EP (1947) Standardized radiological pelvimetry, I. Quantitative aspects. Br. J. Radiol. *20:*45–54.

Arsuaga JL and Carretero JM (1994) Multivariate analysis of the sexual dimorphism of the hip bone in a modern human population and in early hominids. Am. J. Phys. Anthropol. *93:*241–257.

Bohrer SP and Daniels SGH (1969) Error introduced by patient rotation in lateral pelvimetry. Br. J. Radiol. *42:*753–756.

Bradley EL and Blackwood LG (1989) Comparing paired data: A simultaneous test for means and variances. Am. Statist. *43:*234–235.

Brinckmann P, Hoefert H, and Jongen H Th (1981) Sex differences in the skeletal geometry of the human pelvis and hip joint. J. Biomech. *14:*427–430.

Caldwell WE, Moloy HC, and Swenson PC (1939) The use of roentgen ray in obstetrics, part II: Anatomical variations in the female pelvis and their classification according to morphology. Am. J. Roentgenol. *41:*505–526.

Flander LB (1978) Univariate and multivariate methods for sexing the sacrum. Am. J. Phys. Anthropol. *49:*103–110.

Gilliam J, Brunt D, MacMillan M, Kinard R, and Montgomery W (1994) Relationship of the pelvic angle to the sacral angle: Measurement of clinical reliability and validity. JOSPT *20:*193–199.

Greulich WW (1976) Some secular changes in the growth of American-born and native Japanese children. Am. J. Phys. Anthropol. *45:*553–568.

Greulich WW, Thoms H, and Twaddle RC (1939) A study of pelvic type and its relation to body build in white women. JAMA *112:*485–493.

Heyns OS (1947) The influence of x-ray measurements on the pelvic brim index. Br. J. Radiol. *20:*31–33.

Hulth A, Johnell O, and Nilsson BE (1995) Osteoarthritis and late growth. Clin. Orthop. *313:*159–168.

Isçan MY and Cotton TS (1985) The effect of age on determination of race from the pelvis. J. Hum. Evol. *14:*275–282.

Isçan MY, Yoshino M, and Kato S (1994) Sex determination from the tibia: Standards for contemporary Japan. J. Forensic Sci. *39:*785–792.

LaVelle M (1995) Natural selection and developmental sexual variation in the human pelvis. Am. J. Phys. Anthropol. *98:*59–72.

Moerman ML (1981) A longitudinal study of growth in relation to body size and sexual dimorphism in the pelvis. Ph.D. dissertation, University of Michigan.

Murray KA and Murray T (1991) A test of the auricular surface aging technique. J. Forensic Sci. *36:*1162–1169.

Pellico LG and Camacho FJF (1992) Biometry of the anterior border of the human hip bone: Normal values and their use in sex determination. J. Anat. *181:*417–422.

Reynolds E and Hooton EA (1936) Relation of the pelvis to erect posture, an exploratory study. Am. J. Phys. Anthropol. *21:*253–278.

Reynolds HM, Snow CC, and Young JW (1982) Spatial geometry of the human pelvis. Federal Aviation Administration Memorandum Report Number AAC-119-81-5, Oklahoma City, OK.

Reynolds HM, Brodeur R, and Rangarajan N (1995) Pelvic and lumbar posture in a trauma assessment device. Proc. Int. Conf. Pelvic and Lower Extremity Injuries, NHTSA.

Rothschild BM and Rothschild C (1995) Comparison of radiologic and gross examination for detection of cancer in defleshed skeletons. Am. J. Phys. Anthropol. *96:*357–363.

Sibley LM, Armelagos GJ, and Van Gerven DP (1992) Obstetric dimensions of the true pelvis in a medieval population from Sudanese Nubia. Am. J. Phys. Anthropol. *89:*421–430.

Tague RG (1989) Variation in pelvic size between males and females. Am. J. Phys. Anthropol. *80:*59–71.

Thoms H and Greulich W (1940) A comparative study of male and female pelves. Am. J. Obstet. Gynecol. *39:*56–62.

Trotter M and Peterson RR (1967) Transverse diameter of the femur: On roentgenograms and on bones. Clin. Orthop. *52:*233–239.

Webb PAO and Suchey JM (1985) Epiphyseal union of the anterior iliac crest and medial clavicle in a modern multiracial sample of American males and females. Am. J. Phys. Anthropol. *68:*457–466.

Young M and Ince JGH (1940) A radiographic comparison of the male and female pelvis. J. Anat. *74:*374–385.